RESEARCH DEPARTMENT

ELECTRONIC COMPENSATION FOR COLOUR FILM PROCESSING ERRORS

Technological Report No. T-139
(1964/71)

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SUMMARY

The colour accuracy of many existing motion picture films has been found to be inadequate for colour television broadcasting. The causes of error in colour rendering have been investigated and a means has been devised* to permit electrical correction during the television scanning process. Differential adjustments of the colour-separation signals are used to compensate for the errors in any particular film.

1. INTRODUCTION

Television Operations and Maintenance Department, in collaboration with Film Department, have appraised a large number of films with a view to stock-piling material that would be suitable for inclusion in the programmes of a colour television service. Most of the films considered so far have been general release prints of American films intended for optical projection in public cinemas and the survey has shown that many prints have overall colour errors of such magnitude that the picture quality would not be acceptable if judged by the standards at present applied to colour television pictures. The fact that these films appear to be at least marginally acceptable in the cinema, whereas they are not regarded as acceptable for reproduction by television, may be attributable to a number of differences between the two methods of presentation. These are:

(i) In the cinema, films are shown in darkness so that the spectator has no standard with which to compare the displayed colours. Under these conditions, large colour errors can be tolerated, for in nature it is often necessary to make allowance for colour errors due to coloured illumination. (For example, in a forest we rapidly become accustomed to everything being tinged with green by light filtering through the leaves). On the other hand, television is usually viewed in a partly-lit room in which familiar objects are available for comparison. Moreover, error is caused by the fact that the ambient light is usually of a warmer colour (corresponding to a lower colour temperature) than the white of the display, and this error may augment errors of the film.

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* Provisional Patent Application No. 32529/64

(ii) Optical projection appears to reduce the overall gamma of the displayed picture, whereas the overall gamma of a colour television system is usually somewhat greater than unity.

(iii) Colour film in the cinema has already established, in the minds of viewers, a standard of colour fidelity which is, in fact, not very high, but the novelty of colour television is such that viewers, particularly those without technical knowledge of the process, are very critical of colour fidelity.

2. GENERAL CONSIDERATIONS

The overall contrast ratio of a colour television system, including the display tube viewed under conditions of low ambient lighting, is such that adequate tracking of the three colour-separation channels is required over a contrast of at least 30 : 1. In the extreme highlights and extreme dark tones, divergences from the required power law, overloading, etc., give rise to colour errors and it has for some time been considered desirable to restrict the contrast of televised scenes so as not to exceed the capabilities of the television system. Examination of many samples of colour film intended for cinema presentation reveals, however, that the colour prints themselves suffer from similar distortions when the subject matter to be portrayed is of very high contrast. Again, most of the distortion is found at the extremes of the luminance range; in addition, many films also carry an overall colour cast which is particularly disturbing.

It was therefore decided to examine samples of colour film which were obviously in error from the point of view of colour fidelity and to attempt to analyse the causes of these errors. Clearly, a most useful pattern for investigating errors in a colour film is an accurately neutral-grey step-wedge exploring the whole of the luminance range of the film stock. Fortunately, Film Department had in their possession many examples of test colour film in which their standard neutral-grey wedge had been included as part of the subject matter, and sample frames of these wedges, together with frames of other scenes taken from the same roll of film, were supplied to Research Department for examination. It was found that the errors of various samples of film could be classified into the following categories:

(i) Excessive general density of the film.

(ii) Inadequate general density of the film.

(iii) Excessive density in one or two of the three constituent emulsion layers with respect to the general density of the film.

(iv) Black crushing in any one or two of the three emulsion layers.

(v) White crushing in any one or two of the three emulsion layers. Allied to white crushing is an effect which might be termed black stretching.

Defects (i) and (ii) are most likely to be attributable to incorrect exposure, either in the camera or at the stage where the negative is contact-printed to an error in film processing, which may have arisen at either the negative or the positive stage. A general source of error from which any of the five defects mentioned above could arise lies in the incorrect selection of filters used to produce a positive print of optimum colour balance from a negative which is judged visually during the printing process. Visual assessment of negatives is carried out by a skilled person known as a 'grader' and although there are many occasions on which the grader may make an incorrect judgement, this does not appear to be a major source of error since the most prominent defects appear to continue throughout a whole roll of film rather than to vary from shot to shot.

The investigation was carried out using a Cintel slide scanner whose outputs were first balanced using a truly neutral film step-wedge. Individual frames of the film under test were then scanned and the output signals from what should have been a neutral-grey wedge were measured by means of an oscilloscope. The signals from each of the three channels, red, green and blue should, of course, have been identical but, in the majority of cases, they were not; Fig. 1 shows a typical result. It will be seen that there are differences in the peak magnitudes of the signals obtained from the red, green and blue channels. More important, however, is the fact that the ninth, and darkest, step is seen to produce substantially different signal levels in the three channels.

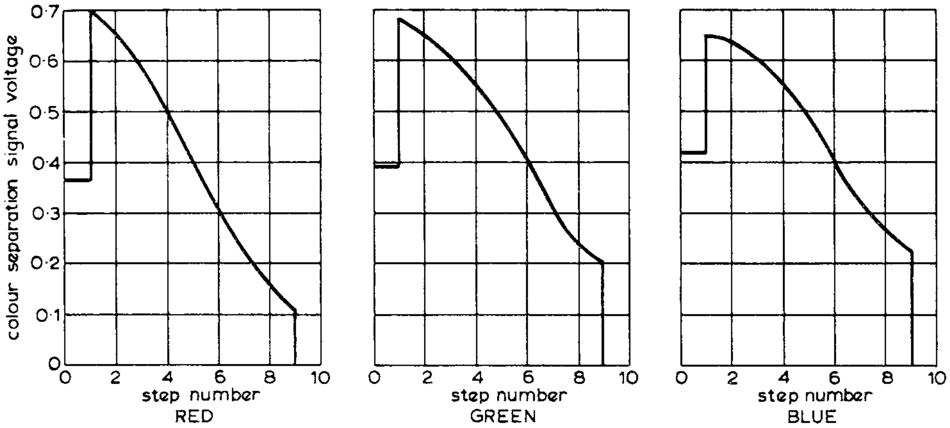


Fig. 1 - Reproduction of grey-scale wedge

This failure to track results in the picture having a colour cast. It will be seen, for example, that the white step (No. 1) would appear to be slightly orange, whereas the bottom step (No. 9) would appear to be cyan, with small departures from neutral-grey occurring on many of the steps. A significant improvement could be made by adjustment of the individual lift and gain controls of the red, green and blue channels of the film scanner, but deliberate misadjustment of the scanner to compensate for errors in one particular film would be most undesirable from the operational point of view.

The present designs of flying-spot film and slide scanners are such that considerable time and effort are required to align the three channels to be objectively accurate in gamma and tracking throughout the contrast range; balancing of the three gamma-correction circuits, for example, can only be achieved successfully if calibration waveforms are fed in and the outputs compared by means of a differential amplifier. It is regarded as operationally essential that film and slide scanners be set up on grey-scale wedges which are known to be truly neutral and that the outputs of the three channels are adjusted to be as accurately matched as refined measurement techniques permit. The philosophy underlying any device intended to introduce compensation for errors in individual examples of colour film should be such that it is entirely separate from the normal adjustment of the film scanner.

3. CORRECTION PROCESSES

Of the errors enumerated in Section 2, the first and second could be compensated by adjustment of master-lift and master-gain controls; these controls would operate equally and simultaneously on all three channels and would be used in the same way as the two corresponding controls found in black-and-white scanners. Present-day flying-spot colour scanners do, in fact, incorporate coarse master-gain controls but, as yet, no master-lift controls have been provided by the manufacturers. It was therefore decided that the apparatus for correcting errors in the film should incorporate two such controls. The third error (i.e. excessive density in one or two of the three emulsion layers) demands differential adjustments and may be corrected by increasing the gain of the appropriate colour-separation signal channel, or channels. Similarly, the fourth and fifth errors (i.e. black crushing and white crushing with black stretching) are tracking errors in the film which require, for their compensation, differential adjustment of the contrast laws of the individual colour-signal channels. The errors may be corrected by passing one or two of the colour-separation signals, obtained from the scanner, through suitable non-linear circuits before they are fed to the coding apparatus. It is, of course, very desirable that the correcting apparatus should not have a great multiplicity of controls, and differential adjustment of the gain or the contrast law in an individual colour channel should, if possible, be carried out by means of one control, rather than three. It is possible to use either three controls with some form of mechanical linkage or a multibank switch which allows selection from a sufficiently large number of predetermined degrees of unbalance; the latter approach is used in the experimental equipment described below.

4. CIRCUIT DETAILS

Fig. 2 is a simplified block diagram of an experimental corrector that has been constructed, showing only those parts which are concerned directly with the colour-separation signals.

The master-gain control consists of three precision ganged attenuators, each attenuator being followed by an amplifier of fixed gain. Each attenuator (and associated amplifier) is indicated by the letter A in Fig. 2.

The master-lift control operates by adding equal blanking pulses, of appropriate polarity, to all three signals in the adders marked C in Fig. 2. The magnitude and polarity of the blanking is determined by a single control marked 'master-lift'.

Compensation for colour casts mainly visible in the lower density parts of the film (i.e. the picture highlights) is carried out in the 'colour gain' section.

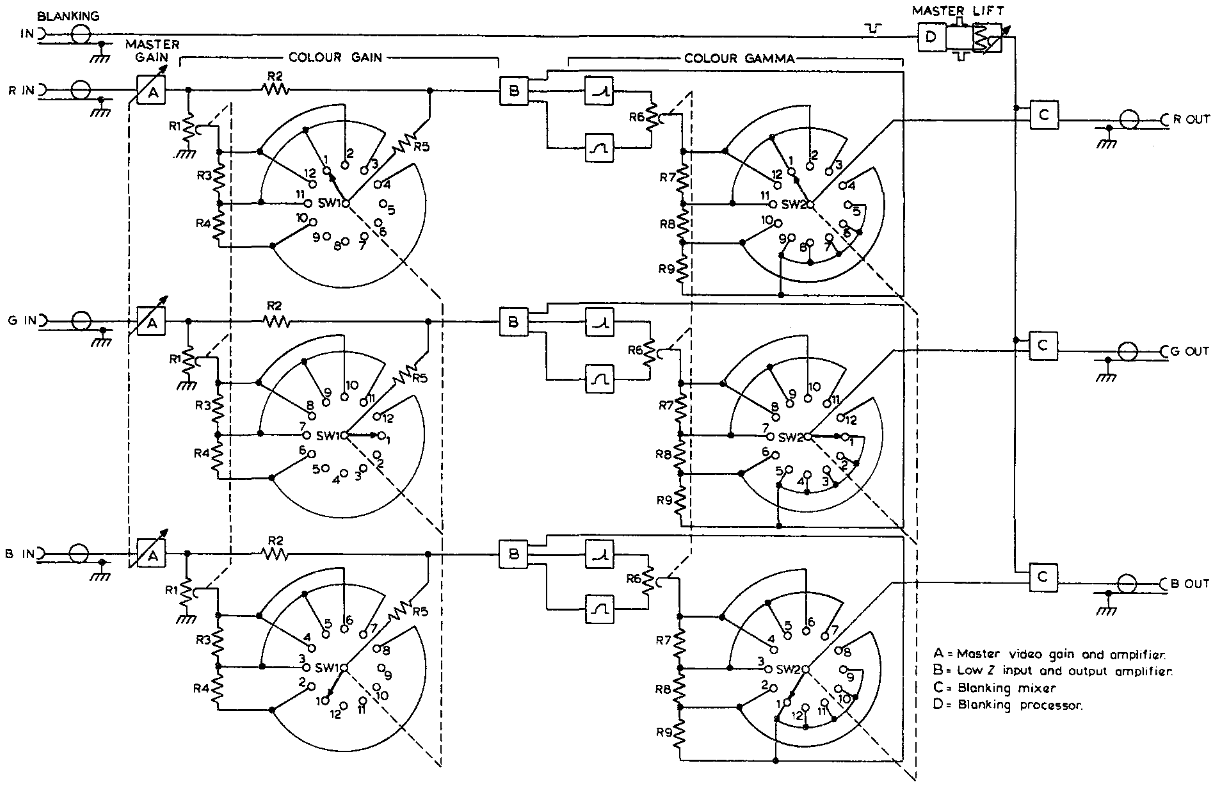


Fig. 2 - Block schematic diagram

Two controls are associated with this process. The first of these is a twelve-position switch which selects the colour axis along which the white-point given by the three electrical signals may be displaced to compensate for a colour cast in highlights of the film.

The alteration of the white-point is achieved by suitable increases of gain in one or two of the three colour channels. Twelve different combinations of gains are available for selection by the switch and the combinations chosen are such that they represent colour axes spaced 30° apart on Maxwell's colour triangle where the red, green and blue primaries are equi-spaced at 120° as shown in Fig. 3. In this particular method of representing colours, equal distances or equal angles on the diagram do not correspond closely with equal visual sensations but it is found in practice that the change of hue between one switch position and the next is always sufficiently small to enable a satisfactory correction to be made. The displacement of the white-point is determined by the additional gain applied to the selected colour channels and the second control in the 'colour gain' section (R1 of Fig. 2) varies the value of μ shown in the equations in Fig. 3. The effect of increasing μ is to increase the saturation of the compensating colour.

With additional switching, it would be possible to make each switch position give a constant value of luminance signal for any given saturation of the compensating colour, but again the variations are not serious in practice, using the coefficients of μ as shown in Fig. 3.

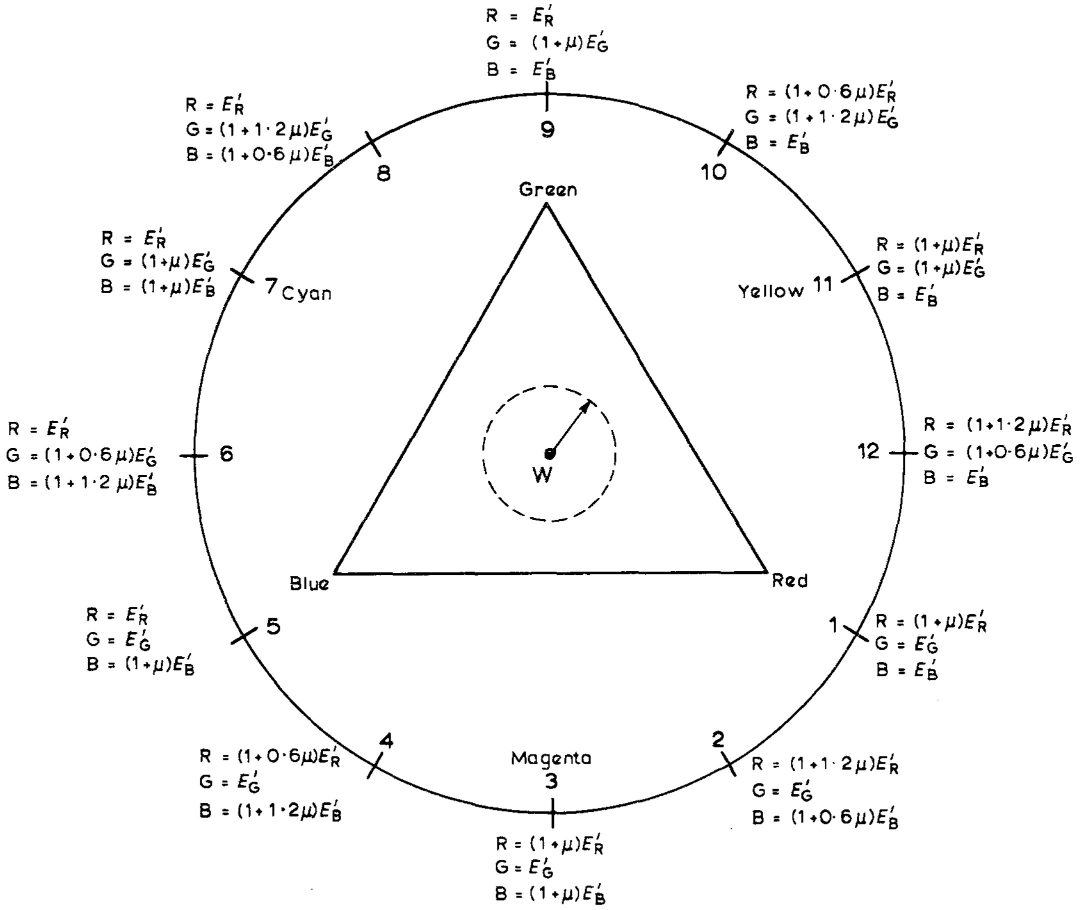


Fig. 3 - Colour axes of switch positions

R G B = Corrected output signals
E'_R E'_G E'_B = Input signals from film scanner
μ = Magnitude of white-point displacement

It is, however, important that the hue selected by means of the switch should remain constant for any saturation and to achieve this, the ratio of the extra gains (not the overall gains) in the two colour channels must remain constant at all values of μ. This requirement is met by the circuit comprising R1, R2, R3, R4 and R5 and the amplifier B of Fig. 2. As already stated, the magnitude of the correction is adjusted by means of the three-gang potentiometer R1. The operation of the circuit may be described by considering the red channel only. If the slider of R1 is connected to the junction of A and R2, maximum correction is applied. B is an amplifier having a low input impedance, so that a variation in the effective value of R2 causes a change in the signal current that flows into the amplifier when correction is being applied. The effective change of R2 is achieved by means of one wafer of the switch SW1 and the fixed resistors R3, R4 and R5. The following table shows the circuit constants in the red channel for each of the twelve switch positions.

POSITION	RESISTORS IN PARALLEL WITH R2
1	R 5 + R 3
2	R 5
3	R 5 + R 3
4	R 5 + R 3 + R 4
5	Open circuit
6	Open circuit
7	Open circuit
8	Open circuit
9	Open circuit
10	R 5 + R 3 + R 4
11	R 5 + R 3
12	R 5

The changes of gain in the green and blue separation-signal channels are carried out in a corresponding manner.

When the slider of R1 is connected to earth, R5 (with, in some cases R3 and R4) is in parallel with the input impedance of amplifier B. This impedance is very low compared with R5 and therefore the effect of R5 on the overall gain is negligible.

The twelve-position, three-gang switch SW1 and the three-gang potentiometer R1 allow the white of the film to be corrected. The application of black-stretch or black-crush compensation is carried out in a manner similar to that used for differential control of gain in the three channels. In this application of non-linear

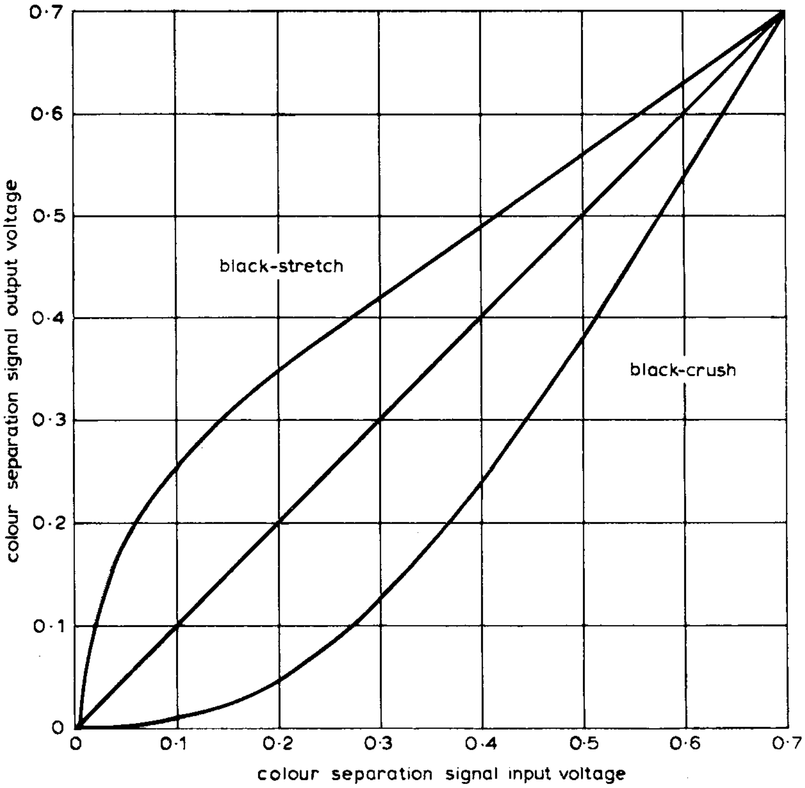


Fig. 4 - Black-stretch and black-crush characteristics

correction to the signals derived from the film, the black-stretch condition is employed to improve tracking of the three signals when the film generally exhibits distortion of the black-crushing type; correspondingly, if the film generally shows black-stretch distortion, the black-crushing condition is selected instead.

The non-linear compensation arrangements can be seen in Fig. 2 where the appropriate section of the diagram is marked 'colour gamma'. Amplifier B feeds two non-linear circuits, having black-crush and black-stretch characteristics respectively; these characteristics are shown in Fig. 4. The two non-linear signals are available at either end of the potentiometer R6 and movement of the slider of this control permits a smooth transition from maximum black-stretch to maximum black-crush through a central position where the effective transfer characteristic of the complete circuit is approximately linear. As in the case of gain control, a twelve-position three-gang switch SW2 selects the colour axis along which non-linear compensation is applied.

5. AN EXAMPLE OF CORRECTION

Fig. 5(a) shows the uncorrected colour-separation signals derived by scanning

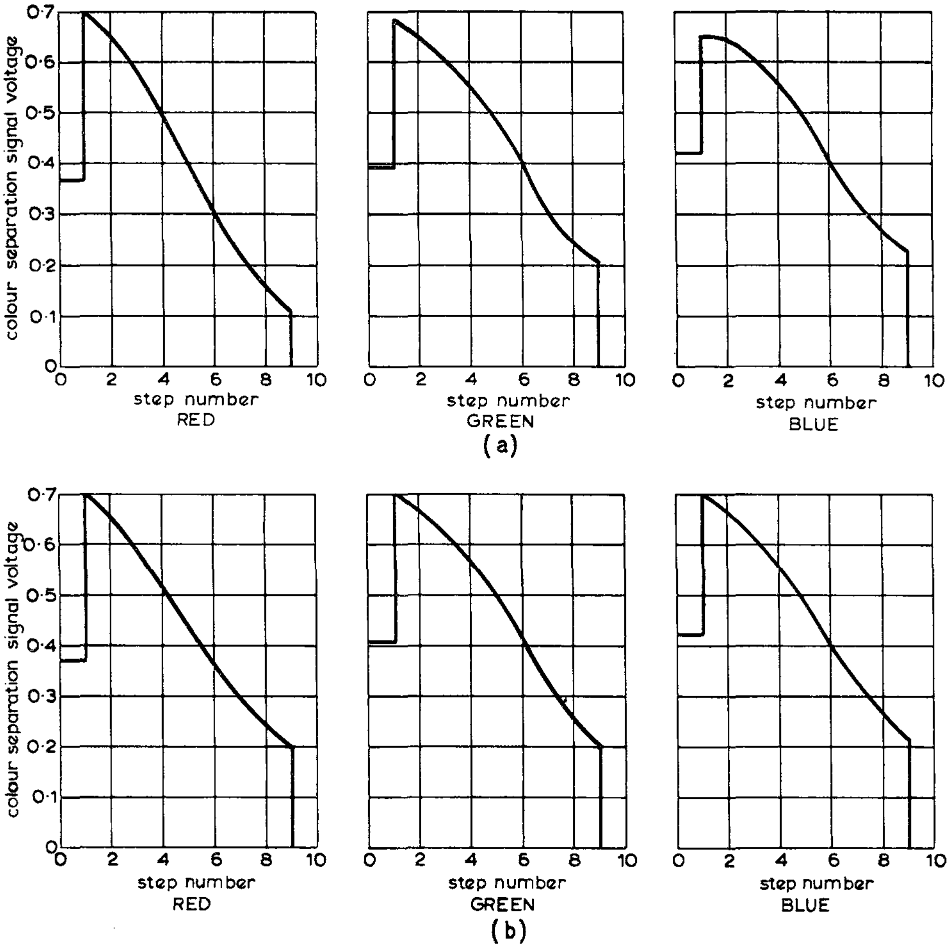
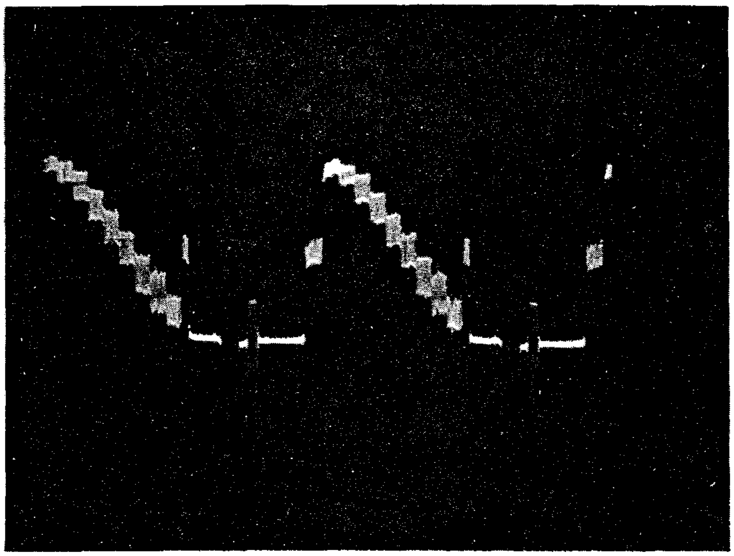
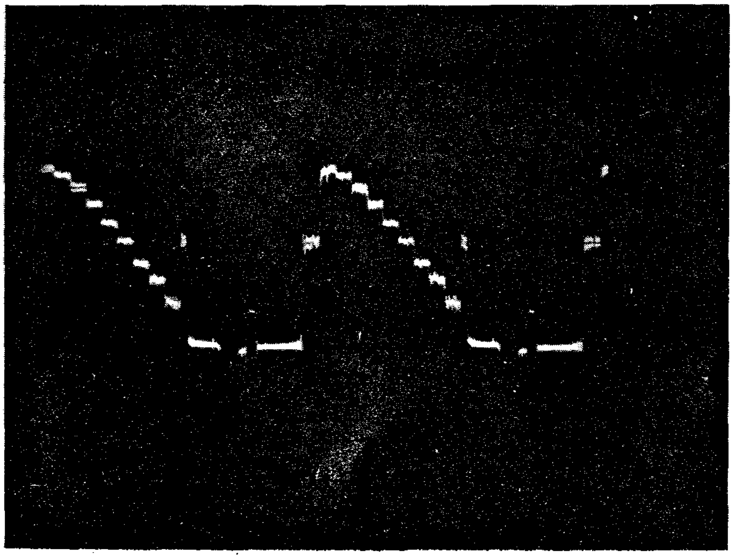


Fig. 5 - Reproduction of grey-scale wedge

(a) Before correction
(b) After correction



(a)



(b)

Fig. 6 - E.I.A. grey-scale wedge

(a) Before correction
(b) After correction

a frame of film that has been exposed to the E.I.A. logarithmic grey-scale chart. These are, in fact, the waveforms shown in Fig. 1 and they show typical distortions encountered in practice. Fig. 5(b) shows the colour-separation signals after correction and it will be seen that the errors have been much reduced. The correction has been achieved by applying black-stretch to the red channel, together with a small amount of cyan/blue gain. (Position 6 of the colour-gain switch of Figs. 2 and 3).

Fig. 6 shows NTSC composite colour-signal line waveforms corresponding to the same grey-scale, both before and after correction. This illustrates a useful way of adjusting the apparatus for minimum colour error, since a truly neutral-grey step-wedge should cause subcarrier to be absent from the NTSC composite signal. Adjustment of the controls for minimum subcarrier ensures that there is minimum colour cast on the wedge.

It is found in practice that, if a grey-scale wedge is photographed at the head of each roll of film under the same lighting conditions and is processed as a single operation with the picture material, adjustment for neutrality of the wedge will ensure that any colour bias of the pictures of the scene is substantially removed.

6. CONCLUSIONS

The simple gain and contrast-law corrections used in an experimental version of the apparatus described appear to provide satisfactory compensation for errors in a large number of examples of film which have been examined.

The availability of a grey-scale at the head of each roll of colour film greatly simplifies the correction procedure. It is, of course, essential that the film of this grey-scale be exposed and processed in the same way as the remaining subject matter. Provided such a grey-scale is rendered neutral by application of the electronic compensation described, an acceptable rendition of the coloured scene will be obtained.

Where theatre release prints are to be corrected, a neutral-grey step-wedge is not available and the settings of the compensation controls are dependent upon the subjective judgement of some operator. In practice, this is found to be less difficult than might be expected and it is suggested that, if this apparatus were to be used under operational conditions, optimum settings could be determined during the rehearsal of the film. It is not suggested that adjustments should be made during transmission. From the large variety of examples of film which have been provided by Film Department and the staff of S.E.Tel.Rec., there seems to be little doubt that a significant improvement can be made in the colour rendering of films which have hitherto been regarded as of marginal acceptability for colour television presentation.

7. ACKNOWLEDGEMENTS

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